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(Reaffirmed 2003)

Indian Standard

METHODS OF MEASUREMENTS OF ELECTRICAL CHARACTERISTICS OF MICROWAVE TUBES

PART I COMMON TO ALL MICROWAVE TUBES

(*First Revision*)

UDC 621·385·6 : 621·317·3

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IS : 6134 (Part I) - 1978
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Indian Standard

METHODS OF MEASUREMENTS OF ELECTRICAL CHARACTERISTICS OF MICROWAVE TUBES

PART I COMMON TO ALL MICROWAVE TUBES

(First Revision)

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(*Continued on page* 2)

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Indian Standard

METHODS OF MEASUREMENTS OF ELECTRICAL CHARACTERISTICS OF MICROWAVE TUBES

PART I COMMON TO ALL MICROWAVE TUBES

(First Revision)

0. FOREWORD

0.1 This Indian Standard (Part I) (First Revision) was adopted by the Indian Standards Institution on 8 December 1978, after the draft finalized by the Electron Tubes Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 The general conditions, precautions to be taken and methods of measurements common to all microwave tubes were originally covered in IS : 6134 (Part I/Sec 1)-1971* and IS : 6134 (Part I/Sec 2)-1972†. A few of the measurements were still under consideration. This revision is undertaken to update the measurement procedures specified and also to include additional measurements taking into account the latest trend at International Electrotechnical Commission level.

0.2.1 Methods of measurements of specific characteristics of individual types of microwave tubes like oscillator tubes, amplifier tubes are covered in individual standard in accordance with the details given below:

IS : 6134 (Part II)-1973 Methods of measurement on microwave tubes: Part II Oscillator tubes.

IS : 6134 (Part III)-1973 Methods of measurement on microwave tubes: Part III Amplifier tubes.

IS : 6134 (Part V)-1978 Methods of measurements on microwave tubes: Part V Parasitic noise.

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*Methods of measurement on microwave tubes: Part I General measurements, Section 1 General conditions and precautions for measurements.

†Methods of measurements on microwave tubes: Part I General measurements, Section 2 Common to all devices.

0.3 While preparing this standard assistance has been derived from the following IEC Publications, issued by International Electrotechnical Commission:

IEC Pub 235-2 (1972) Measurement of the electrical properties of microwave tubes: Part 2 General measurements

IEC Pub 235-2B (1975) Second supplement to Publication 235-2 (1972)

IEC Pub 235-2C (1976) Third supplement to Publication 235-2 (1972)

0.4 In reporting the result of a test made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

1. SCOPE

1.1 This standard (Part I) deals with methods of measurements of electrical characteristics which are common to all types of microwave tubes. This standard also covers general requirements and precautions to 'be taken, for making measurements on microwave tubes.

2. TERMINOLOGY

2.0 For the purpose of this standard, the terms and definitions given in IS : 1885 (Part IV/Sec 1)-1973† and IS : 1885 (Part IV/Sec 3)-1970‡ shall apply in addition to the following.

2.1 **Heater Modulation Effect** — The modulation of the output caused by an ac heater current or by ripples on a dc heater current.

2.2 **Heater Modulation Factor** — The heater modulation factor is expressed as:

a) the amplitude modulation depth at '*n*' hertz per ampere of heater/ripple current; and/or

b) the phase modulation index at '*n*' hertz per ampere of heater/ripple current; and

c) in case of oscillator tubes also as the frequency modulation excursion at '*n*' hertz per ampere of heater/ripple current;

where '*n*' is the relevant frequency component of the ac heater current or ripple on a dc heater current.

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*Rules for rounding off numerical values (revised).

†Electrotechnical vocabulary: Part IV Electron tubes, Section 1 Common terms.

‡Electrotechnical vocabulary: Part IV Electron tubes, Section 3 Microwave tubes.

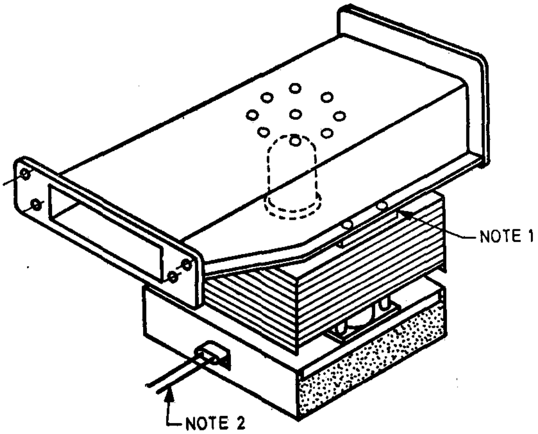
2.3 Frequency Sensitivity to Electrode Voltage Variations (Voltage Coefficient of Frequency) — The ratio between the change in frequency of oscillation and the causative change of voltage at a stated electrode, thermal effects excluded.

NOTE — If the stated electrode is intended for frequency controlling purposes the voltage coefficient of frequency is named electronic tuning sensitivity.

2.4 **Enclosure** — The accessible outer surface of the electronic tube including stated parts of the microwave connecting circuits or an arbitrary but stated surface used for reference in the measurement.

NOTE 1 — For example, see Fig. 1, 2 and 3.

NOTE 2 — The enclosure may be the tube envelope and may also include any high voltage or X-radiation shielding recommended by the tube manufacturer. When the enclosure is not a part of the tube envelope or of the X-ray or high-voltage shielding, it should be made from electromagnetically transparent material.



NOTE 1 — Output coupler box is only a part of the enclosure if it is a permanent part of the tube. Leakage at the junction of the coupler box and tube shall be checked.

NOTE 2 -**Leakage** from the leads shall be checked at the enclosure. Take adequate preacution against high-voltage hazard.

FIG. 1 TYPICAL MICROWAVE ENCLOSURE OF A C. W. MAGNETRON

2.5 Effective Aperture — The effective area through which the power flux couples to the sensor (sensing element) of the power-flux density meter.

2.6 **Proximity Distance** — In the far field of a calibration source, the centre-to-centre distance between two sensors (equally distant from the source) at which the reading of one instrument is changed by ± 2dB from its indication in the absence of the other instrument.

NOTE- **This is an approximate measure of the major dimension of the effective aperture.**

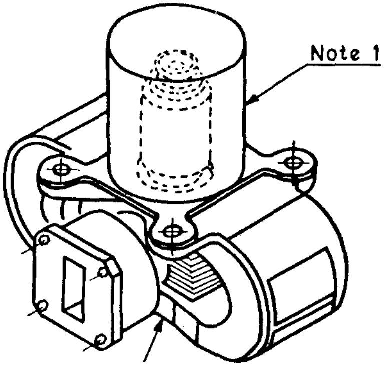
2.7 **Spacer Tip** — An adapter which ensures a constant distance between the sensor and the surface of the enclosure to be measured.

3. AMBIENT CONDITIONS FOR MEASUREMENTS

3.1 All measurements should preferably he carried out under the following ambient atmospheric conditions:

Temperature	Between 15 and 35°C
Relative humidity	Between 45 and 75 percent
Atmospheric pressure	Between 86 and 106 kPa (1 kPa = 10 mbar)

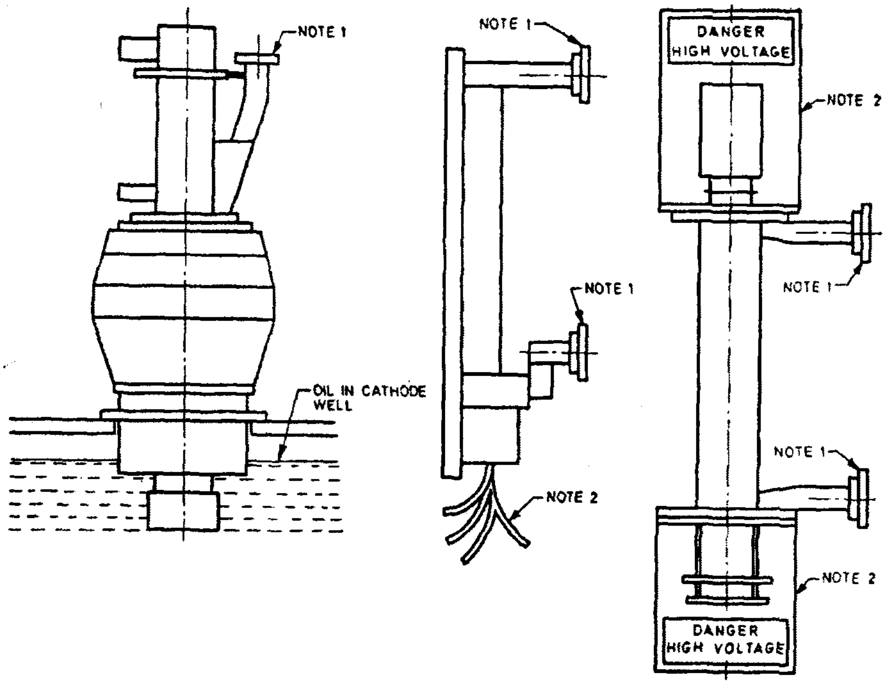
NOTE — **The actual ambient conditions under which measurements are carried out shall be noted.**



NOTE 1 — **Cathode well is not a part of enclosure though the seal to gasket plate is a part of it and shall be checked.**

NOTE 2 — **Flange joint shall be checked.**

FIG. 2 TYPICAL ENCLOSURE FOR A PULSE MAGNETRON



NOTE 1 — Waveguide flange joints or cable connections which are a part of the tube should not leak microwave power.

NOTE 2 — Flying leads or transparent high-voltage shields are parts of the enclosures.

NOTE 3 — Cathode well is not a part of the enclosure.

FIG. 3 TYPICAL MICROWAVE ENCLOSURES FOR KLYSTRONS AND TRAVELLING WAVE TUBES

4. GENERAL REQUIREMENTS FOR MEASURING EQUIPMENT

4.1 Measuring Equipment — Critical microwave components and instruments like test mounts, directional couplers, frequency meters, standing-wave detectors, attenuators, bolometer and crystal mounts, loads and transmission-line adapters, etc, to be used in the measurement, should be checked for proper match [voltage-standing wave ratio (VSWR)] over the required frequency band and power level. In particular, loads, with their associated transmission-line adapters, if any, should be carefully checked for the specified degree of matching (VSWR) over the required frequency band and power level.

4.1.1 It should also be ensured that none of the microwave components and instruments is likely to be subjected, during the measurement, to microwave power or temperature, or both, exceeding its ratings.

4.1.2 The internal surfaces (wherever they are accessible for inspection and cleaning) of these components and instruments as well as the mating surfaces of their flanges and connectors, should be checked against presence of any dust, obstruction, etc, prior to their assembly. They should be assembled together as straight and square as possible and should be supported adequately at suitable points.

4.1.2.1 When coaxial line assemblies are used, these should be checked to ensure continuities in both inner and outer conductors, as well as impedance matching over the required frequency band. When two transmission lines of different sizes or types have to be coupled together a suitable impedance transformer that covers the required frequency band should be used.

4.1.3 It is desirable that the complete measuring equipment shall be checked for proper match (VSWR) over the required frequency-band whilst any tunable or adjustable components and instruments are tuned or adjusted over their appropriate ranges.

4.1.4 The accuracy of the measuring equipment shall be in conformity with the required precision. Unless otherwise specified, it shall be atleast four times better than the required precision of the parameter being measured.

4.1.5 The characteristics including tolerances ofmicrowave components like attenuators, couplers, etc, used for measurements, shall be known and taken into account while estimating the overall error of the parameter being measured.

4.2 The low frequency output, coupling and display circuits shall have time constants, or pulse response characteristics, which do not affect the measurements.

4.3 Any measuring device used should be protected in such a way that stray electromagnetic fields have a negligible effect on its performance.

4.4 All test equipments, components, etc, should be suitably earthed as required.

4.5 Precaution — In measuring devices that are resonant or have high VSWR values, particular care shall be taken to avoid frequency pulling or amplitude variations caused by reflections from the systems, including the load. Uncertainty error arising due to mismatch in the measuring system during power measurements should be taken note of,

5. MOUNTING/SETTING UP OF MICROWAVE TUBE FOR MEASUREMENT

5.1 The instructions and precautions as specified by the manufacturer relating to mounting/setting up of the tube for measurement shall be followed. The general procedure and precautions are given in Appendix A, for guidance.

6. TEMPERATURE CONDITIONS

6.1 The temperature conditions required during measurements shall be stated.

6.1.1 As a general precaution, where operating temperatures are not stated, it is good practice to ensure that the temperature of the body or reference surface of the tube does not exceed 125°C.

6.1.2 Where the measurement of temperature is required for operating conditions or temperature coefficients, it is necessary to measure the temperature at a stated part of the tube in addition to measuring the ambient temperature. This is because of the large variation in cooling efficiency with the rate of flow and turbulence of the cooling medium.

6.1.3 It is also necessary to maintain steady conditions for a sufficient time to ensure that all parts of the tube have reached their equilibrium temperature.

6.2 **Forced Cooling --** When forced cooling is required, the following should be quoted:

a) Type of coolant;

b) Method of application;

c) Rate of Row, or pressure difference between inlet and outlet at stated ambient conditions;

d) Limits of inlet or outlet temperature; and

e) Maximum permitted body temperature of the tube at a stated point.

7. PRESSURIZING

7.1 Where pressurizing is required, the following items should receive attention before and during operation of the tube:

a) The system shall be clean and free from condensates and be capable of adequate sealing to maintain gas purity.

b) The minimum or maximum limits of gas pressure to which the microwave components can be subjected without damage or mechanical distortion shall be observed.

c) The nature, purity, dryness and temperature of the gas shall be within stated limits.

7.1.1 ***Precautions*** — In the presence of arcing, certain gases used in pressurization dissociate and release quantities of toxic gas; adequate ventilation is, therefore, essential in such cases.

8. RADIATION HAZARDS

8.1 Radio Frequency Radiation

8.1.1 Radio frequency power may be emitted not only through the normal output coupling but also through other apertures. Such leakage in microwave tubes may occur due to the inadequacy of the microwave isolation of tube electrode terminals inadequacy of the closure of the microwave circuits themselves and the imperfect shielding of the microwave connectors associated with input and output circuits. When the tube is operated with grounded anode to obtain the consequent reduction in high-voltage hazard, the user may come in such proximity to the tube as to encounter hazard from microwave power leaking from the tube or system. Such radiation may also occur if the tube is functioning incorrectly. This leakage power may be sufficiently intense to cause danger to the human body, particularly to the eyes. Looking into the device for any reason, for example, for observation of cathode temperature or possible arcing, may seriously endanger the eyesight. If it is essential to make such observations, adequate radio frequency screening must be used.

8.1.2 Screening may be by the use of copper gauze whose mesh is small compared to the radiation wavelength; alternatively, observations may be made through a small hole or an attenuating tube set in the wall of the output waveguide, for example at a suitable bend.

8.1.3 In general, the absorption of radiation by body tissues is a function of the wavelength and, for comparable radiated power, the danger may vary considerably with wavelength.

8.1.3.1 Under certain conditions of operation there may be unwanted radiations at wavelengths other than that for the proper mode of operations, which may be harmful to body tissues.

8.1.3.2 The measurement of RF/microwave leakage from integral circuit electron tubes shall be in accordance with Indian Standard methods of measurement of RF/microwave leakage from integral circuit electron tubes (*under preparation*).

8.2 X-Radiation

8.2.1 A highly dangerous intensity of X-rays may be emitted by tubes operating on voltages higher than approximately 5 kV. Adequate protection (X-ray shielding) for the operator is then necessary. Information concerning the possible intensity of X-rays should always be noted carefully.

8.2.1.1 The emission intensity of X-rays may correspond to a value of applied voltage much higher than that expected from the actual value applied to the anode.

8.2.2 When visual observations are being made through an aperture, it is important to provide protection to the eye; for example, by interposing a suitable piece of lead glass.

9. HIGH VOLTAGE HAZARDS

9.1 A large number of microwave tubes operate at high voltages (up to several tens of kilovolts). Personnel making measurements on these tubes, shall be familiar with the dangers involved, and also with the necessary precautions to be taken while working with such high voltages.

10. METHODS OF MEASUREMENTS

10.1 Power

10.1.1 *Mean RF Output Power -The* mean output power is measured with the tube operating under stated conditions.

The measurement of power may be made by either of the methods given in **10.1.1.1** and 10.1.1.2.

10.1.1.1 *Method 1 — Direct method (Calorimetric method)* — In this method it is intended that the whole of the output power be dissipated as heat in a calorimetric load. Provisions for measuring the rate of dissipation of this heat should be such that RF and thermal losses are avoided. For example, where a liquid forms or cools the load, the following equation applies:

$$P = c\,(t_2 - t_1)\,m$$

where

P = output power in watts,

t_1 = temperature of ingoing liquid in °C,

t_2 = temperature of outgoing liquid in °C,

c = specific heat capacity of liquid in joules per kilogram degree, and

m = rate of flow of liquid in kilograms per second.

NOTE 1 — This method is generally suitable for measuring average power levels above a few hundreds of milliwatts.

NOTE 2 -When the thermal losses are not negligible or cannot be avoided, the method given in Appendix B shall be followed to take these losses into account.

10.1.1.2 *Method 2 — Indirect mefhod (Bolometric method) (thermistors, barretters, etc) -For* the measurement of output power, power meters using temperature-sensitive devices such as barretters or thermistors should preferably be used.

The device and its mount should be calibrated relative to known standard power-measuring device. As barretters are easily damaged by overloading, they are not recommended for the measurement of power under pulsed conditions.

With the bridge at balance, the mount shall be matched to ensure accurate measurements over the required bandwidth. If the conditions of best bolometer match and maximum bolometer output do not coincide, the condition of maximum bolometer output may be used provided that precautions are taken to ensure that no unwanted mismatch effects occur.

NOTE -This method is generally suitable for measuring low average power levels up to few hundreds of milliwatts.

10.1.1.3 *Precautions -The* following precautions shall be taken:

a) If the power measuring or indicating instrument is tunable, an isolator, directional coupler, or attenuator should be inserted between the instrument and the tube in order to prevent tuning from causing frequency pulling or variation of the reflection coefficient of the load circuit.

b) It is preferable to use a self-balancing bridge to avoid the effects on other measurements of standing waves caused by resistance changes.

c) Considerable errors in the measurement results may arise at the higher frequencies because of the effect of losses in the mount, including thermal losses from the bolometer, and the difference in the bolometer temperature distribution with the substitution power as compared with the microwave power. These errors can be eliminated only by calibration against a standard.

d) The calibration of directional couplers and other attenuating elements should be undertaken with the bolometer matched and in the same environment as will apply during the measurements.

e) The power measuring device should have sufficient inertia, that is, it should be insensitive to rapid power fluctuations. This is particularly important in pulse operation and in tubes with an ac supply.

10.1.2 *Pulse Output Power* — This is obtained by measuring:

a) the mean output power in accordance with **10.1.1**, and

b) the duty factor.

$$\text{Then pulse output power} = \frac{\text{Mean output power}}{\text{Duty factor}}$$

10.1.3 *Peak Output Power (Peak Envelope Power)* — In this measurement a peak-reading diode voltmeter is loosely coupled through suitable directional couplers to the output lines. The voltmeter reads the peak value of the voltage corresponding to the output power. The voltmeter should be calibrated with c.w. (unmodulated) power within the desired range.

If a c. w. power source of enough power to permit calibration up to the desired peak value is not available, the calibration curve of voltmeter reading *versus* power obtained at a lower level may be extended to the desired level by the addition of suitable calibrated directional couplers. In this case, linearity of the amplitude response of the peak-reading voltmeter up to the desired range of indication should be assured for the frequency of measurement.

10.1.3.1 *Precautions* — The following precautions shall be taken:

a) The input time constant of the peak-power meter shall be sufficiently long to exclude spikes.

b) The time constant of the output circuit, across which the rectified voltage appears, should be sufficiently longer than the interval between successive peaks occurring in the modulated signal to ensure that further increase in time constant does not change the indicated value.

10.1.4 *Power Stability* — The output power (P_1) is measured as in **10.1.1**. The H. T. supply is switched off for a stated period of time. The H. T. is then re-applied without further adjustment and the output power (P_2) is measured again after temperature equilibrium has been reached.

The power stability is expressed as:

$$\left[1 - \frac{|P_2 - P_1|}{P_1} \right] \times 100 \text{ percent}$$

10.1.5 *Emission Stability* — The tube is operated under stated conditions and the output power, cathode, current, or frequency is measured. The heater or filament voltage is then lowered by a stated amount and the output power, cathode current or frequency is again measured after a stated interval of time. The change in the measured quantity is a measure of the emission stability.

10.1.6 *Amplitude Sensitivity to Electrode Voltage Variation* (*AM/ΔV, or AVAM coefficient, or amplitude sensitivity*)

10.1.6.1 *Output power sensitivity to variation of an electrode voltage* — The tube is operated under stated conditions. When thermal stability is achieved the output power is measured, the voltage at a stated electrode is then varied by a stated amount and the resultant output power is measured when thermal stability is achieved.

The result of the measurement is expressed in watts per volt, or decibels per volt, or as the ratio of a change in power to the causative change in electrode voltage.

10.1.6.2 *Output power sensitivity to modulation of an electrode voltage* — The tube is operated under stated conditions. When thermal stability is achieved the voltage at a stated electrode is modulated by a stated amount and the consequent variation in output power is measured. The rate of change of voltage must be high enough to exclude thermal effects.

The result of the measurement is expressed in watts per volt, or decibels per volt, or as the ratio of change in power to the causative change in electrode voltage.

10.2 **Pulse Characteristics -The** measuring devices should be, so arranged that pulse distortion introduced by their presence is negligible.

In the measurement of the performance of a pulse-modulated tube it is necessary to establish the characteristics of the applied voltage pulse, the pulse waveform of the current drawn by the tube and the envelope of the resulting output pulse.

Because of the relative amplitudes of the current, voltage and output pulses depend upon the nature of the electronic interaction, the pulse definitions applicable to the particular tube type should be used.

10.2.1 *Voltage Pulse Characteristics (Applied)* — Measurement of the voltage pulse characteristics may be made by any suitable method, including either:

a) peak diode voltmeter method, or

b) C.R.O. display method.

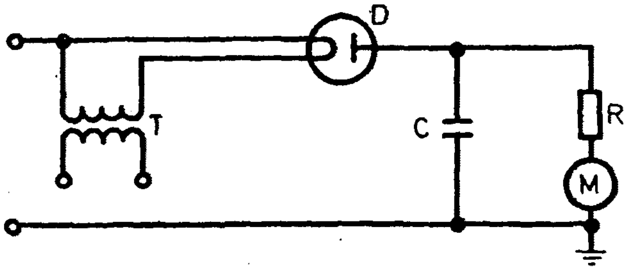
Both of these methods may be used with the instrument connected directly across the circuit being measured or, where high voltages make this impracticable, a resistive or capacitive dividing network may be used. The choice of method will depend on the value of the peak voltage being measured and on the characteristics of the pulses as well as on the effect of the instrumentation, as part of the load, upon the supply.

Method 1 — Peak diode voltmeter method

For measurement of the amplitude of repetitive pulses the peak diode voltmeter circuit as shown in Fig. 4, is recommended. The peak inverse voltage rating of the diode under pulsed conditions should exceed the maximum pulse voltage plus any backswing voltage which may occur. In general practice, the application of this method is limited to pulse voltages below approximately 35 kV.

The diode should be chosen to have adequate current carrying capacity (at its nominal heater voltage in case of a tube diode). A high dynamic impedence of the diode may prevent full charging of the capacitors before the end of the pulse. In the case of a tube diode, the capacitive load on the pulse generator will be the capacitance of the diode plus the capacitance of the heater transformer, which should be suitably insulated to withstand the pulse voltage.

The time constant *RC* should be at least two orders of magnitude greater than the time between pulses. The resistor *R* should be chosen so that the load on the pulse generator is small and will usually have a value of many hundreds of megohms. The capacitor should have a voltage rating greater than the value of the pulse amplitude to be measured and, in order to reduce serious inductive effects, should be made up of an RF type of capacitor (generally available only in small values) in parallel with the main capacitor.



NOTE — The connection of the diode should be in accordance with the polarity of the voltage being measured.

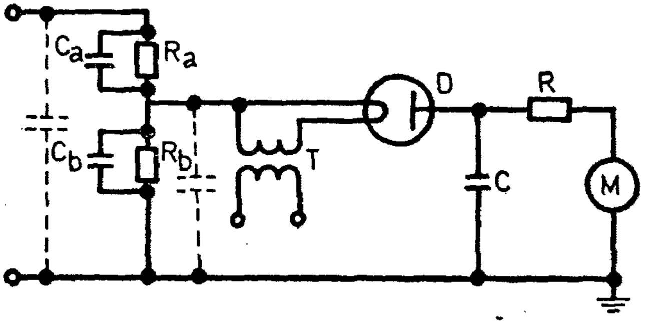
FIG. 4 CIRCUIT ARRANGEMENT FOR PEAK DIODE VOLTMETER METHOD

The circuit may be calibrated with a dc voltage or by a resistor of known value and an accurately calibrated current meter. It is also recommended that the C. R. O. display method be used to check against deformation of the pulse shape, which may introduce undesirable effects.

The extension of this method to voltages higher than about 35 kV is shown in Fig. 5, which uses a resistor divider network. The resistors R_a and R_b should be non-inductive and should be chosen so that the diode operates within its voltage rating. It may be necessary to insert capacitors C_a and C_b such that the time constants of the two sections of the divider are equal. The effective impedance of the diode circuit is in shunt with R_b and C_b during the pulse and its effect should be taken into account. In order to minimize the distortion of the pulse, the time constant of the input capacitance of the whole peak voltmeter circuit and its input resistance should be less than one-fourth of the pulse duration.

If a spike occurs on the voltage pulse, resistance should be added in series with the peak voltmeter (*see* Fig. 6). The correct value of this resistance R_c can best be determined by observing the change in meter reading with increase in resistance (*see* Fig. 7).

The accuracy may be improved if the components of the circuit and shunt used are enclosed in a dust-free, temperature-regulated compartment, with suitable mounting arrangements or oilbaths to avoid corona.

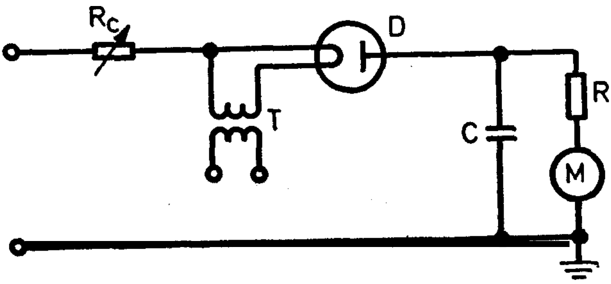


D = diode whose ratings are suitable for the voltage appearing across Rb,

R_a, R_b = voltage divider.

C_a, C_b = capacitors added such that R_a, C_a = R_b, C_b

FIG. 5 CIRCUIT ARRANGEMENT FOR PEAK DIODE VOLTMETER METHODS (HIGH VOLTAGE)



NOTE — The connection of the diode should be in accordance with the polarity of the voltage being measured.

FIG. 6 ALTERNATIVE CIRCUIT ARRANGEMENT FOR PEAK DIODE VOLTMETER METHOD

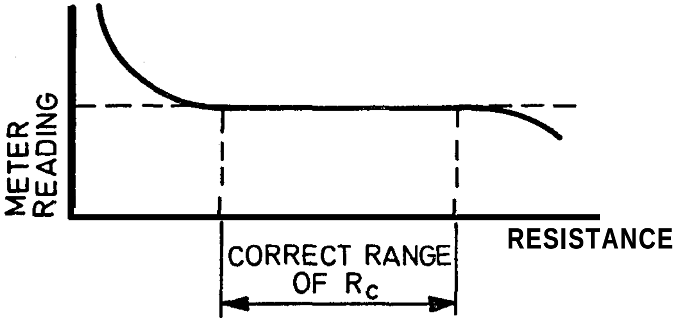


FIG. 7 CORRECT VALUE OF RESISTANCE FOR REMOVAL OF VOLTAGE SPIKE

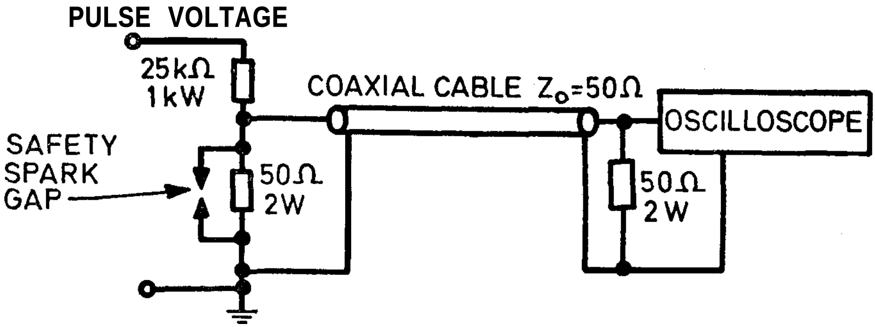
Method 2 — Cathode-ray Oscilloscope (C. R. 0.) Display Method

The C. R. 0. with a suitable *divider,* can be used to measure the characteristics of the pulse shape, for example, duration, rise time, fall time and amplitude.

Details of suitable divider circuits are as follows:

a) *Resistive divider circuit (see Fig. 8)*

The total resistance should be kept low enough to avoid errors caused by the input capacitance of the C.R.O.; in general, the total resistance should not be higher than 40 000 ohms. Preferred range is 10 000 ohms to 25 000 ohms. The dissipation within the divider network is higher than would be expected with a flat-top pulse, and a factor of 2·5 times the expected dissipation is recommended. Care should be taken to reduce the effects of inductance by the use of suitable resistors (for example, deposited-film carbon resistors) and of corona by the use of suitable mounting arrangements or oil baths where required.



NOTE — **Numerical values shown are illustrative only.**

FIG. 8 CIRCUIT ARRANGEMENT FOR OSCILLOSCOPE DISPLAY METHOD WITH RESISTIVE DIVIDER NETWORK

The connecting cable to the C. R. 0. should be matched at both ends in order to avoid distortion in the display. When this cannot be done a resistance shall be added in series with the sending end of the cable. A suitable spark gap should be included in order to protect the operator and the C. R. 0. from high voltage if the divider network becomes open-circuited.

NOTE — **It is generally suitable for pulse lengths between 0·5 to 10 μs and duty cycles of the order of 0·001. The method is not suitable for testing low power pulse tube because the additional loading on the modulator is excessive.**

b) ***Capacitive divider circuit (see Fig. 9)***

This is particularly useful at very short pulse duration. Its use for longer pulse duration is restricted by the amount of pulse droop which can be tolerated.

The divider is made up of a capacitor C_1 developing a high voltage in series with a capacitor C_2 developing a low voltage, the divider ratio being approximately inversely proportional to the ratio of the capacitances. The divider network is connected to the C. R. 0. through a series matching resistor R, a coaxial cable and, if necessary, a blocking capacitor C_3. The input resistance of C. R. 0. should be two or three orders of magnitude larger than R. The capacitor C_1 has a value usually in the range of 1 to 10 pF and should be shielded to avoid stray pickup. The dielectric may be ceramic, resin, oil or vacuum, as required by the working voltage. The capacitor C_2 should have very low inductance and a safety spark gap should be connected across this capacitor. The divider circuit may be calibrated using other methods described; for example, the resistive divider or peak voltmeter method within its range, using a suitable pulse duration and with the errors caused by the known characteristics of the methods minimised.

For pulse duration down to about 0·05 μs, the length of the coaxial cable should not exceed that which has a two-way transit time of about one tenth of the pulse duration. For pulse durations below about 0·05 μs, the cable length becomes impracticably short and the divider may then be mounted directly on the C. R. 0.

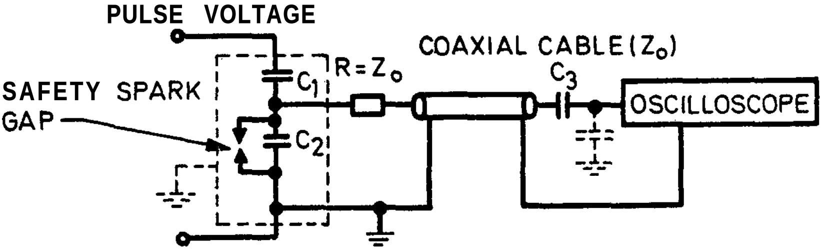


Fig. 9 Circuit Arrangement for Oscilloscope Display Method with Capacitive Divider Network

c) ***Balanced divider circuit* (*see Fig.* 10)**

This is particularly useful when the pulse waveform is to be faithfully reproduced in detail.

The divider consists of a high voltage section R_1 and C_1, and a low voltage section R_2 and C_2, and the C. R. 0. matching components. The time constants of the two sections, including the effects of stray impedances shall be equal. Usually, the value of R_2 is made equal to the characteristic impedance of the coupling line between the divider network and the C. R. 0. In this case the resistance R_3 in the diagram is zero, and $R_4 = R_2$. This gives a division ratio $2R_1/R_2 = C_2/C_1$. The time constants of the two circuits are $R_1 C_1$ and $\frac{1}{2} R_2 C_2$ respectively.

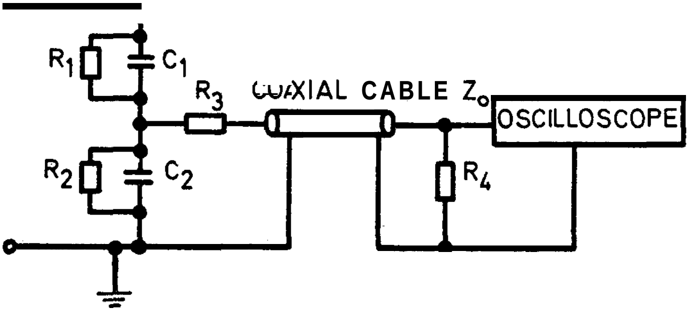


FIG. 10 CIRCUIT ARRANGEMENT FOR OSCILLOSCOPE DISPLAY METHOD WITH BALANCED DIVIDER NETWORK

When available equipment requires that the value of R_2 be less than the connector cable impedance Z_o, an additional non-reactive resistor R_3 must be added at the sending end of the cable. The division ratio is:

$$\frac{R_2 R_4}{R_1 (R_2 + R_3 + R_4) + R_2 (R_3 + R_4)}$$

‘The time constants are then: R_1C_1 and $R' C_2$, where

$$R' = \frac{R_2 (R_3 + R_4)}{(R_2 + R_3 + R_4)}$$

It is difficult to use this circuit when R_2 exceeds Z_o of the cable.

When assembled, the divider is checked for division ratio and for pulse distortion caused by possibly over-looked stray impedance effects. This may be done using a calibrated square-wave generator whose rise and fall time characteristics are similar to those of the pulse to be measured.

Alternatively, calibrated signal sources in the frequency range extending from zero up to twice the reciprocal of the pulse duration may be used.

NOTE — In practice it may be useful to isolate the divider network from cable and the C. R. 0. by using a value of R_3 several times greater than Z_o.

10.2.1.1 *Rate of rise of voltage pulse* — The rate of rise of voltage pulse can be measured by any of the following two methods:

Method 1 — Capacitive Divider Circuit

This method makes direct use of method 2 (b) (capacitive divider circuit) given in 10.2.1 using the minimum possible value of C_1 consistent with:

a) the provision of an adequate deflection potential to be supplied to the oscilloscope;

b) minimum capacitive loading of the pulse source; and

c) freedom from unwanted inputs due to stray capacitive pick-up. (Capacitor C_1 should be shielded so as to minimize this effect.)

Provided that these precautions are taken, the measured rate-of-rise of voltage pulse is not materially different from that when the measurement equipment is not connected to the pulse source.

The rate-of-rise can be determined by direct measurement of the displayed pulse.

NOTE — A large value of C_1 reduces the rate-of-rise of voltage. In extreme cases it may be desirable to measure the rate-of-rise of voltage pulse at various values of C_1 so that an extrapolation to zero capacitance can be accomplished.

Method 2 — Differentiator circuit

Theory

Since the rate-of-rise of pulse voltage is defined mathematically by a derivative representing a change of pulse quantity with respect to time, a differentiating circuit may be used (*see* Fig. 11).

The differentiating element consists of a capacitor C and a resistor R_1, the output of which is viewed on an oscilloscope having a calibrated line display and associated metering system.

Subject to certain restrictions, the rate-of-rise of the voltage pulse can be found from the voltage output V_0 of the differentiator by means of the following relation:

$$\frac{dv}{dt} = \frac{V_0}{RC}$$

where C is the capacitance of the differentiator and R is the resultant resistance of the parallel combination of R_1 and the resistance of the matching network to the transmission line.

The restrictions are as follows:

a) the differentiator time constant $R (C + C_{out})$ shall be much smaller than the pulse rise time, one-tenth or less;

b) the reactance of the differentiator capacitance C shall be high relative to the output impedance of the pulse source and the load combined, at all frequencies up to the reciprocal of the pulse rise time.

NOTE — In practical cases, the transmission line to the oscilloscope will effect the differentiating net-work. The effect will be minimized by using $R_1 = Z_0$.

In order to prevent the problems arising from reflections, it is recommended that both end of the line be matched, in which case:

$$\frac{dv}{dt} = \frac{2V_0}{R_1 C}$$

Measurement

The measuring equipment is arranged so that the output of the voltage divider and the output of the differentiator can be displayed on a calibrated oscilloscope (see Fig. 11).

The rate-of-rise of the voltage pulse at a stated voltage level can then be calculated by use of the formula given in **10.2.1.1** (Method 2).

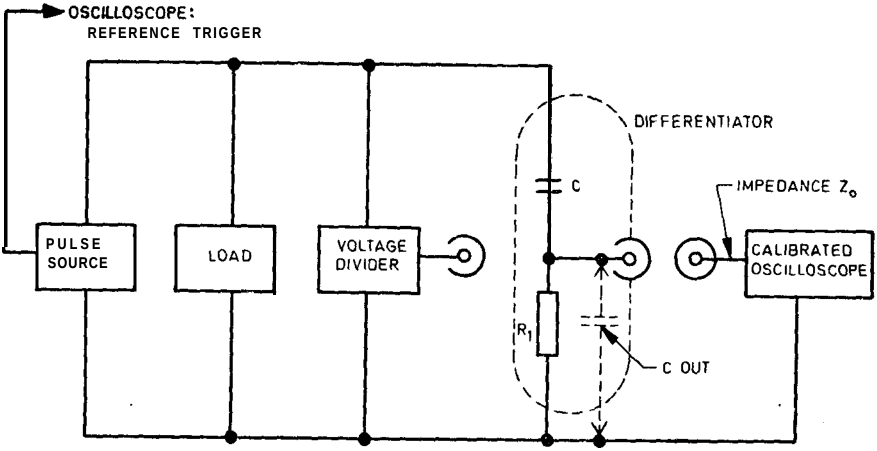


FIG. 11 MEASUREMENT OF RATE OF RISE OF VOLTAGE PULSE METHOD 2 : DIFFERENTIATOR CIRCUIT

Precautions — The following precautions shall be taken:

a) All the cables in the system should be matched at both ends;

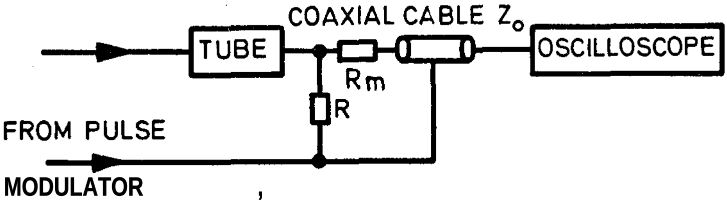
b) In order to select the voltage level at which to measure the rate-of-rise it is necessary to synchronize the display of the derivative dv/dt, and the leading edge of the pulse being measured; and

c) The oscilloscope shall be such that the time base is stable and is not triggered by extraneous causes. Its bandwidth shall be sufficient to allow the pulse and the derivative to be displayed without linear distortion, and the resolution shall be adequate to allow accurate measurement.

10.2.2 ***Current-Pulse Characteristics*** — Pulse amplitude, pulse duration, ripple on the pulse, time of rise and time of fall of the current pulse can be measured by displaying the current pulse on an oscilloscope in either of the recommended circuits shown in Fig. 12A and 12E.

The current-viewing resistor ***R*** in Fig. 12A should be designed and constructed with special precautions to achieve negligible inductance. The value of the resistor ***R*** should be sufficiently small so that capacitance between the external waveguide and earth does not modify the wave shape.

The stray capacitance of the current transformer in Fig. 12B should be sufficiently small so that the observed waveform of the pulse is not modified from the original. Care should be taken to avoid unwanted voltages caused by stray fields.

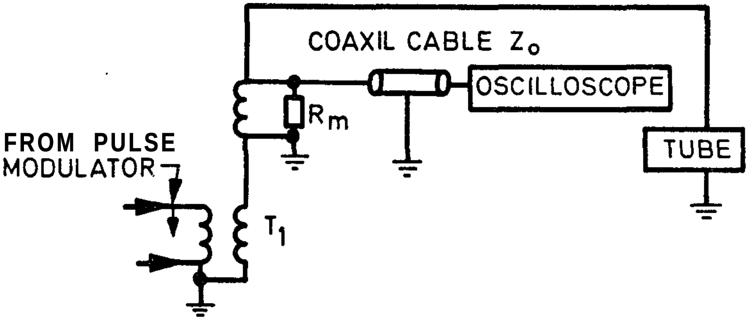


$R_m + R = Z_0$

R = Current viewing resistor

R_m = Cable-matching resistor

12A Circuit for Observation of Current Pulse



$R_m = Z_0$

T_1 = **Pulse** transformer

T_2 = Current transformer

12B Alternative Circuit for Observation of Current Pulse

FIG. 12 CIRCUITS FOR OBSERVATION OF CURRENT PULSE

10.2.3 *RF Output Pulse Characteristics* — The envelope of the output pulse is obtained by means of a calibrated microwave detector of suitable bandwidth which is coupled to the output circuit of the tube. When short pulses are being viewed, it is necessary to ensure that the detector bandwidth is adequate. In order to derive the correct value of pulse duration for the calculation of pulse output power, a squarelaw detector should be used. Then the duration, measured at the instants at which the instantaneous values of the pulse equal 50 percent of the pulse amplitude, is used to calculate the duty factor.

If a linear detector is used, the pulse duration is measured between the instants at which the instantaneous values of the pulse equal 70·7 percent of the pulse amplitude.

10.2.4 *Pulse Repetition Frequency* (*P. R. F.*) — This measurement should be made with the greatest possible accuracy in view of its effect on other associated measurements. When ancillary equipment is used this should be checked against standards.

It is preferable to measure the P. R. F. by using pulses from the tube being measured, but when this cannot be done, the correspondence of these pulses with those used for measurement should be checked.

10.2.4.1 *Method 1*— The pulses are counted, using for example a decade counter, and timed with a stop-watch or a crystal-controlled timing device. The maximum counting rate of the counter should exceed the P. R. F. and the counter should have a register that will hold a count corresponding to a period that can be timed with good accuracy. The pulse amplitude and duration should be such as to make the counter operate properly and it may be necessary therefore to obtain pulses for this purpose from one of the driving stages of the tube being measured. Typical accuracy to be expected with a stop-watch can be better than 1 percent, but with a crystal-controlled timing device the accuracy can be ± 1 pulse per counting interval.

10.2.4.2 *Method 2* — The modulator may be driven by an external calibrated oscillator.

10.2.4.3 *Method 3* — A calibrated oscillator is connected to the *X* and *Y* plates of an oscilloscope through phase shifting circuits so that an elliptical Lissajous figure is displayed. (Any other time base generator should be disconnected from the *X* plates for the measurement.) The pulses are injected into the circuit of the *Y* plates and if the pulse signal rotates round the Lissajous figure, the frequency of the oscillator is adjusted to the P. R. F. or any integral sub-multiple of the P. R. F. The pulse signal will then become stationary.

For example, if the oscillator sub-multiple of the **P.R.F.** is adjusted to one half of the P. R. F., two stationary pulses symmetrically spaced around the Lissajous figure are displayed. In general, for any integral sub-multiple of the P. R. F. the same integral number of stationary pulses will be displayed. This method is capable of great accuracy.

10.2.4.4 *Method 4* — The interval between successive pulses is measured by use of the calibrated time base of an oscilloscope. It is recommended that the frequency of the calibration wave be not less than 25 times the P. R. F. so that the visual interpolation meets the required accuracy. The trace should be examined by time-base expansion to ensure that the reference frequency has been set up to an exact integral sub-multiple of the P. R. F. being measured. When the calibration frequency has been correctly adjusted no trace will appear across the base of the displayed pulses.

10.2.5 *Duty Factor* — The duration of the 'on' active condition is measured by means of a suitably calibrated oscilloscope (see **10.2.1, 10.2.2** and 10.2.3 as appropriate). The total number of 'on' active conditions which occur over a required period, termed the averaging period, is obtained by use of an accurate counting system. The duty factor is then derived from the quotient of the summation of the 'on' active condition periods occurring during the averaging period, by the averaging period.

For the observation of the total number of 'on' active-condition periods, the provisions of 10.2.4 may be applied.

It is desirable that the duty factor be maintained as near as possible to the stated value. If small discrepancies of pulse duration introduce deviations outside this accuracy, compensation may be effected by adjustment of the pulse repetition frequency.

10.2.6 *Arcing* — Arcs are recorded by a counter activated by an arc detector. The arc detector should be adjusted to respond to pulse current that rises to a specified value above normal operating pulse current. A measure of arcing is the number of arcs counted during a prescribed period under stated operating conditions.

10.3 Frequency — The device used for measuring frequency should not appreciably affect the operation of the tube being measured.

The probable degree of overall accuracy of the frequency determination should be known and stated when results are quoted. Account should be taken of errors caused by associated instruments, the observer and the frequency meter itself.

If the tube is pulsed, a cavity wavemeter is a convenient means of measuring the centre frequency of the spectrum. For more accurate measurement, the centre frequency of the spectrum can be compared with the frequency of a c. w. source of high precision.

NOTE — For the purpose of converting frequencies to wave-lengths the common value of $c = 3 \times 10^8$ m/s may be insufficiently accurate and $c = 2{\cdot}998 \times 10^8$ m/s should then be used.

10.3.1 *Spectrum Width*-A small signal, sampled from the output circuit through a directional coupler or other suitable coupling device, is fed to a spectrum analyzer. The coupling device should be such that it does not affect the electrical characteristics of the load of the tube.

The width of the envelope of the spectrum is measured between points of stated level (usually at quarter of full power) and the reference level is determined by means of a calibrated variable attenuator inserted before the first detector in the R F circuit connecting the coupler and the analyzer.

To calibrate the spectrum analyzer with respect to the level of the measuring points, the amplitude of the major lobe of the displayed envelope is depressed by adjusting the attenuation to the required value.

10.3.2 *Frequency Sensitivity to Electrode Voltage Variation (FM/ΔV, or ΔV-FM Coefficient, or Frequency Sensitivity)*

10.3.2.1 *C. W. operation* — The tube is operated under stated conditions. The stated electrode voltage is periodically varied at such a rate that thermal effects may be neglected. A frequency discriminator and a calibrated oscilloscope are used to display the frequency as a function of the electrode voltage. The voltage coefficient of frequency is then derived from the slope of the curve observed on the oscilloscope and expressed in MHz per volt.

The frequency variation for the electrode voltage variations may also be measured either with a spectrum analyzer or a calibrated narrow-band receiver.

10.3.2.2 *Pulse operation* — The tube is operated under stated conditions. The amplitude of the voltage pulse applied to the stated electrode is modulated. The rate of modulation shall be high enough to avoid thermal effects and low enough to avoid side-band effects.

The difference between the extremes of the pulse amplitude is measured in accordance with 10.2.1.

The differences between the extremes of frequency of oscillation is measured with a spectrum analyzer or a calibrated narrow-band receiver.

The result of the measurement is the ratio of the difference between the extremes of frequency of oscillation, to the difference between the extremes of the voltage pulse amplitude expressed in MHz per volt.

10.4 Heater Modulation Effect — This effect is of importance in an oscillator type of tube from the frequency stability point of view, whereas in an amplifier type of tube the significant effect may be one of amplitude and/or phase modulation.

The tube is connected to a transmission system terminated by a matched load. A matched mixer, coupled into an I. F. amplifier, is suitably fed from the transmission system. The amplifier output is applied to an appropriate detector circuit followed by a narrow-band ac amplifier tuned to the required ripple frequency component.

The tube is operated at the reference frequency under optimum output power conditions. The control electrode voltages are supplied from a dc source having no significant ripple voltage superimposed. The heaters should be dc supplied and a known amount of ac ripple superimposed at the required frequency. With tubes intended for ac heating, an ac voltage may be used for this measurement.

The peak-to-peak amplitude of the ac amplifier output voltage, is measured.

10.4.1 *Heater Amplitude-Modulation Factor* — For this measurement the detector is a linear detector whose output is applied to a resistance (R_1) in series with a dc milliammeter. The voltage across R_1 is observed by means of a suitable indicator.

The heater amplitude-modulation factor is then :

$$\frac{E}{I_1 R_L G I_2}$$

where

E = peak-to-peak ac amplifier output voltage,
R_L = detector load resistance,
G = gain of amplifier connected across R_L,
I_1 = detector dc current, and
I_2 = peak-to-peak value of ac ripple superimposed on the heaters.

10.4.2 *Heater Frequency-Modulation Factor* — In this measurement the detector is a frequency discriminator calibrated in conjunction with an ac amplifier. The frequency discriminator is preceded by a suitable limiter. The amplitude of the ac amplifier output voltage is measured and converted into equivalent frequency deviation. The result is expressed as the rms frequency deviation expressed in Hz per ampere of heater ripple current.

This may be written as:

$$\sqrt{\frac{\Sigma\ (\Delta f)^2}{N^2}}\ \text{Hz per ampere}$$

where

N = the number of observations, and

Δf = the frequency deviation in any observation.

With the tubes intended for ac heating, an ac voltage may be used for this measurement.

When the frequency deviation is small and may possibly be obscured by random effects, it may be desirable to use a transmission-line bridge system similar to that shown in Fig. 13. The bridge output and a reference signal are each applied to similar high-gain linear amplifiers. After amplification the two signals are applied to a phase-sensitive detector circuit and the output is measured.

10.4.3 *Heater Phase-Modulation Factor* — This measurement is similar to that in **9.5.2**, but the detector should be of the phase-comparison type calibrated in conjunction with an ac amplifier.

10.5 Parasitic Noise — Under consideration.

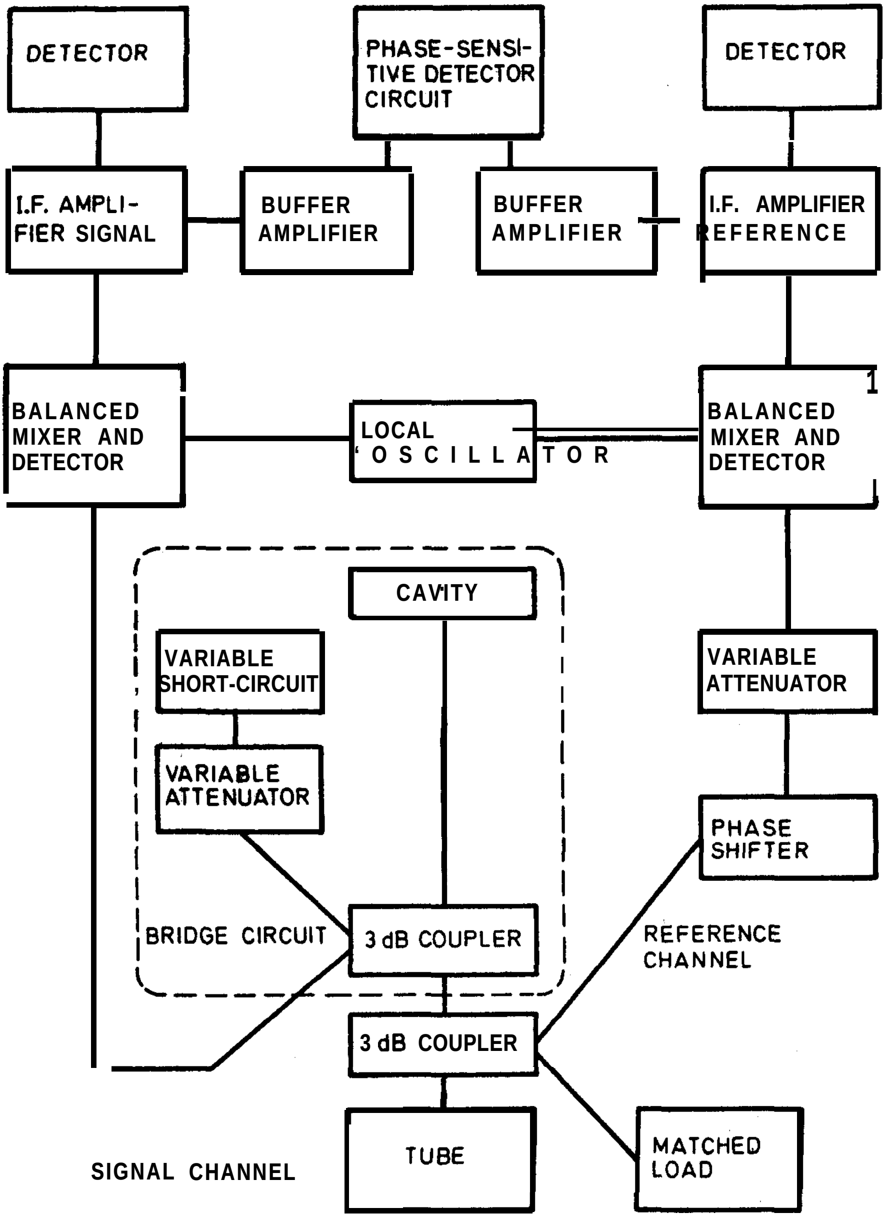


FIG. 13 SCHEMATIC DIAGRAM FOR SENSITIVE FREQUENCY MODULATION MEASUREMENTS

APPENDIX A

(*Clause* 5.1)

GENERAL PROCEDURES AND PRECAUTIONS FOR MOUNTING/SETTING UP OF MICROWAVE TUBES FOR MEASUREMENT

A-1. GENERAL

A-1.1 The general instructions and precautions shall be as follows:

a) The tube shall be securely mounted and grounded.

b) All connections shall be made properly, special care shall be taken in respect of connections for:

   i) high voltage(s);

   ii) heater supply and other tube components, such as, grids, focus, electrodes, soles, accelerators, collectors, and repellers;

   iii) RF output load system;

   iv) RF drive connection, if an amplifier, to the tube under test; and

   v) external magnets or solenoids.

c) Specified cooling shall be provided through all cooling systems.

d) Pressurizing shall be turned on and arc detectors activated, when needed.

e) Heater supply shall be turned on in such a manner that the rated maximum heater current is not exceeded. (Some heater systems allow heater snap-on by use of inherant current limitation.)

f) Magnetic field supply shall be turned on, and adjusted as required in tubes using solenoids.

g) The electrode to be grounded may be either the cathode or the anode as given in relevant specifications. However, it is common to operate the cathode below ground, with the anode and collector at ground, although some collectors may be depressed in potential towards cathode potential. The cothode is generally the reference point for voltages. The operating currents and voltages are indicated on the individual tube, accompanying data sheet, or relevant specifications.

A-2. APPLICATION OF VOLTAGES

A-2.1 Tubes Without Control Electrodes Magnetrons, Travelling-wave Tubes, Klystrons, etc) — The operating voltages are turned on as given in relevant specifications and adjusted to operate the tube at the specified value of the indicated parameter. Unless abrupt application of voltage is specifically required, it is preferable to raise the voltage (direct or pulse) slowly, especially if the tube has been inoperative, or in storage, for some time (which may be specified by the manufacturer).

A-2.2 **Tubes With Control Electrodes —** The instructions and precautions for the tubes with control electrodes shall be as follows:

- a) If the specified control electrode voltage is positive relative to the cathode, all other voltages are applied first in any specified, otherwise desired, sequence.
- b) If the control electrode is negative with respect to the cathode, the beam control electrode voltage should first be biased to cut off the beam current at the desired operating condition; other voltages are then applied approximately simultaneously.
- c) The control electrode voltage is adjusted until the required cathode current is reached.
- d) If required, the heater input power is adjusted downward to compensate for heating due to back bombardment.
- e) Removal of voltages may be simultaneous or in the reverse order of application. For some high-power tubes, it may be necessary to arrange removal of the magnetic field and cooling to follow removal of the tube voltages and in a specified programmed manner.
- f) Upon completion of testing, liquid for cooling (if used), shall be completely drained and all protective covers shall be attached.

APPENDIX B

[*Clause* **10.1.1.1** (*Note* 2)]

METHOD OF MEASUREMENT OF MEAN RF OUTPUT POWER (CONSIDERING THERMAL LOSSES)

When heat losses from the load and from the cooling liquid are not negligible the calibration of the calorimeter shall take these losses into account by the following method:

A liquid flow rate m_1 kg/s is set, and apparent power P_1 is determined from the equation given in **9.1.1.1.** The flow is adjusted to a different rate m_2 (about half or twice m_1 is convenient) and apparent power P_2 is determined. If $P_1 = P_2$ there is no significant cooling error. If $P_1 \neq P_2$ the true power P is given by:

$$P = \frac{P_1^{m_1/(m_1 - m_2)}}{P_2^{m_2/(m_1 - m_2)}}$$

$$\text{or } (m_1 - m_2) \log P = m_1 \log P_1 - m_2 \log P_2$$

From a pair of readings, a general correction factor $K(m)$ for any flow rate can be plotted using the equation:

$$K(m) = P/P(m) = (P_1/P_2)^{m_1 m_2/m(m_1 - m_2)}$$

where

$P(m)$ is the apparent power at flow m.

Alternatively, the relationship between temperature rise and power dissipated can be determined experimentally by substituting known values of dc or 50 Hz power in the calorimeter system. Test circuit is shown in Fig. 14.

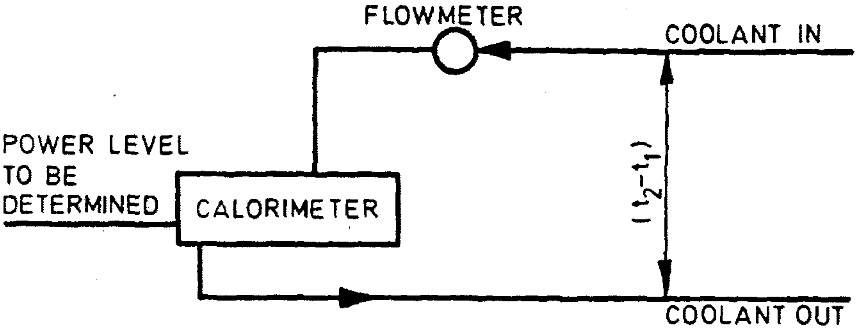


FIG. 14 CALORIMETER METHOD

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Conversion*
Force	newton	N	1 N = 0·101 972 kgf
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2

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